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DATA TRANSMISSION INVESTIGATION
REPORT NO. 5

FIRST QUARTERLY PROGRESS REPORT

11 September 1962 to 10 December 1962

DA PROJECT NO. 3B31-07-001

CONTRACT NO. DA 36-039-SC-90728

(Continuation of Contract No. DA 36-039-SC-87343)

U.S. ARMY SIGNAL RESEARCH
AND DEVELOPMENT LABORATORY,
FORT MONMOUTH, NEW JERSEY

MOTOROLA INC.
Communications Division
4545 W. AUGUSTA BLVD. CHICAGO 51, ILL.

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The objective of this program is to determine the characteristics and distribution of errors in digital data communications systems of the tactical army.

SIGNAL CORPS TECHNICAL REQUIREMENT

SCL-4276, Dated 13 October 1960
and
Amendment No. 1 dated 15 November 1961

Written by: ______________________
J. J. Tsimbidis
Project Engineer

Approved by: ______________________
W. M. Borman
Ass't Chief Engineer

MOTOROLA INC.
Communications Division
4545 W. AUGUSTA BLVD. CHICAGO 51, ILL.

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SECTION I

PURPOSE

The purpose of this project is to investigate the performance of data transmission terminals over tactical military communications systems. Testing of the data terminals and communications systems will take place in the vicinity of Fort Monmouth, New Jersey.

A family of communications systems has been developed for the Army. These systems, designed primarily for voice communications, are to provide the circuits for digital data transmission. The limitations of these systems when functioning as digital data transmission links are to be determined.

Error statistics of the data transmission terminals obtained while operating over the communications system mentioned above are to be evaluated and reported upon. Included in this study is an investigation of the transmission of digital data in the presence of random and impulse noise. The properties of impulse noise are to be studied with the result being the simulation of impulse noise in cable and radio communications systems.

NOTE

This is the first quarterly report for the work performed under the second contractual phase of the program. The work is a continuation of the initial phase which was performed under Contract No. DA 36-039-SC-87343.

SECTION II

ABSTRACT

Performance of the Di-Phase modem in the presence of white noise is evaluated at 150, 300, 600, and 1200 bps. White noise test results are also given for the Quad-Phase modem operating back-to-back and through tandem channels of the AN/TCC-7.

Frequency translation and its effect upon the various modems is discussed. S/N performance curves for each modem for a constant frequency shift shows the loss in performance resulting from operating a modem over a system that exhibits frequency translation.

Problems involved in using the AN/VRC-12 radio set in digital data transmission are discussed with recommended input/output connections and levels for various modes of operation. Use of the AN/VRC-12 in an automated data system is discussed with special treatment given to automatic on-off control of the transmitter.

Field cable test results are presented in tabulated form and are briefly discussed. Results obtained from full duplex operation of two Di-Phase modems operating over the AN/TCC-7 cable system are given. Limitations of the present modems are given and special operator instructions are suggested. Finally, a comparison is made of the AN/TYC-1, Di-Phase, and Quad-Phase modems operating over ten tandem channels of the AN/TCC-7 cable system.

The new data generator and correlator are discussed, and a block diagram of the system is presented. Also, the problems found in the present AN/TRC-24 radio link are discussed and suggestions for future tests in this area are given.

SECTION III

CONFERENCES

On September 7, 1962, a meeting was held between USAERDL and MOTOROLA personnel. The USAERDL representatives were - J. Futerfas, J. Tucker, and J. Duffy; the MOTOROLA representative were - J. Tsimbidis and R. Salava. The main topics of discussion were the status of the program at the end of the first contractual phase and the tests to be performed during the second phase of the program.

The design of the new logging circuits was also discussed. The features to be included in the new circuits and the operating specifications were determined.

SECTION IV

FACTUAL DATA

During this reporting quarter the white noise tests and field tests were continued, frequency translation tests were performed, operation of the AN/VRC-12 was further investigated, and a new data generator and a new data correlator were designed and constructed. The following paragraphs contain a detailed description of the work performed during the quarter.

4.1 FREQUENCY TRANSLATION

Communications systems do not always have a carrier lock between terminals and a shift in the audio signal may be present. The military systems studied thus far (AN/TCC-7 and AN/VRC-12) possess no frequency shift, but other systems such as the AN/USC-3 which is a SSB system do exhibit some frequency shift although it is generally very small. It is therefore necessary that the modem for military use should be able to tolerate a small amount of frequency shift to be capable of operating over most of the existing military communications systems. Tests were carried out during this past quarter on all the modems available to determine the maximum frequency translation that each modem could tolerate on a short term basis and the S/N degradation for a constant frequency shift.

4.1.1 FREQUENCY TRANSLATION TEST SYSTEM

Frequency translation tests were conducted using the system shown in Figure 1 which is the first channel of a AN/TCC-7 terminal connected back-to-back. The only modification to the channel is the carrier input to the receive mixer which is from a signal generator instead of the 8 kc signal from the terminal carrier generator. Thus by controlling the frequency of the signal generator, a fixed amount of frequency shift in the audio signal can be introduced. Using this system, the modem transmitter and receiver are connected to the transmit and receive terminals of the AN/TCC-7 respectively and the frequency shift is introduced by the signal generator. The bit errors caused by this shift are recorded by the error logging circuits while the frequency shift is recorded by a counter measuring the difference between the 8 kc carrier generator and the oscillator frequency.

4.1.2 MAXIMUM FREQUENCY SHIFT FOR EACH MODEM

Results of the tests to determine the maximum frequency shift that each modem can tolerate on a short term basis (5 minute test) are listed in the table below:

Modem	Maximum Frequency Shift
AN/TYC-1 (XC-2)	0
Di-Phase	± 10 cps
Quad-Phase	± 20 cps
VSB	± 500 cps

As noted in the above table, the AN/TYC-1 (XC-2) cannot tolerate any frequency shift. A study of the clock recovery scheme employed by the modem yielded the reason for this result. The bit timing of the modem is based on the 1200 cps "data zero" frequency received rather than on the bit timing of the data. It should be noted that this operation of the modem is not due to the FSK modulation technique used in the modem, but it is due to the clock recovery method.

The Di-Phase modem will tolerate approximately ± 10 cps but it is believed that the modem would tolerate more frequency shift if the character synch technique was not used. As shown in the table, the Quad-Phase modem will tolerate ± 20 cps and the VSB modem will tolerate the most frequency shift. Envelope detection is used by the VSB modem, thus frequency shift has little effect on this modem.

4.1.3 S/N DEGRADATION DUE TO FREQUENCY TRANSLATION

The S/N degradation due to frequency translation in the Di-Phase modem is shown in Figures 2 and 3. The results show that approximately one db degradation is present for a constant 5 cps frequency shift. The resulting S/N curves are compared with the modem performance over one channel of the AN/TCC-7 connected back-to-back with no frequency shift. Figures 4, 5, and 6 show the degradation in the Quad-Phase modem performance at 600, 1200, and 2400 bps respectively for a constant 10 cps frequency shift. About 2 db degradation is noted at 1200 and 2400 bps while at 600 bps approximately 4 db degradation is noted.

Figure 7 shows that the VSB modem is degraded only 1 db for a -100 cps shift while a 1 db improvement in performance is noted for the +100 cps shift. These results may be attributed to the envelope detection scheme in the modem, since the greater the carrier frequency the better the envelope detector will perform.

4.2 AN/VRC-12 TESTS

4.2.1 INPUT/OUTPUT OF THE AN/VRC-12

Various input and output connections are available in the AN/VRC-12 radio set, each of which was designed for a specific purpose. Each possibility was investigated to determine which connections will provide the best operation for digital data transmission. Consideration was given to impedance, level of input, and performance.

The input connections available on the production transceiver model are shown in Figure 8. Provision for turning on the transmitter is available in the front of the unit and in the rear connector (R/T control). Both 150 and 600 ohm output impedance levels are available on the modems.

Test were conducted on both the pre-production model and a production model of an AN/VRC-12 inserting the AN/TYC-1 modem signal in the MIC input (-50 dbm, 150 ohms) and also into the X-mode input (0 dbm, 600 ohms). The modem receiver was connected to the 150 ohm variable output shown in Figure 9 with the output level adjusted to -5 dbm. Continuous transmission of digital data was conducted satisfactorily through both inputs with the transmitter on low power and the receiver separated from the transmitter by approximately six feet. A test was then made with the ON/OFF mode of transmission of data. In the ON/OFF mode of operation a short message is transmitted and then the modem transmitter goes off the air. This procedure is repeated to test the system for initial synchronization. Satisfactory operation with a pre-production AN/VRC-12 was conducted through the X-mode input but not through the MIC input. Photographs of the received sync characters were taken and the results are shown in Figures 10 and 11. Figure 10 shows that the two sync characters are distorted if the signal is applied to the MIC input. This distortion occurs in the automatic gain control (AGC) of the speech amplifier. If the signal is applied into the X-mode input the signal is not distorted.

Similar tests were conducted with a production model of the AN/VRC-12 and the results are shown in Figure 11. While the distortion is less pronounced in this set, it is definitely present. Lowering the input level reduces the AGC effect which can be observed by comparing Figures 11-A and 11-B. Figure 11-C shows the received signal using the X-mode input of the transmitter.

With the AN/TYC-1 modem output applied to the X-mode input the AN/VRC-12 transmitter produced the best error characteristics in the ON/OFF mode of operation. The 3 kc bandpass filter in the transmitter is bypassed when the X-mode input is used thus eliminating any effect this filter may have on the data signal. The wideband ($\approx$20 kc) capability will also be available although at this time the IF of the AN/VRC-12 is presently not designed for this capability. The 0 dbm impedance level of the X-mode also seems best suited for the modems presently available. Thus, in the transmitter, the X-mode input is recommended for the present digital data modems.

In the receiver, two outputs may be used depending upon the type of data transmission desired. Figure 9 shows the output capabilities of the auxiliary receiver of the AN/VRC-12. The X-mode output is best suited for continuous transmission of digital data and also for high speed transmission (above 2400 bps). In a system where it is desired to transmit short messages and then go off the air the X-mode output will not be satisfactory since if no RF carrier is present the X-mode output will be noise at a sufficient level to operate the modem receiver and produce erroneous data. Hence, it is desired to have the squelch circuit operative and the variable output (150 ohms) must be used. The level must be adjusted for a signal level within the range of the modem.

The effect of the squelch with the ON/OFF carrier operation has not been fully investigated although earlier tests have been satisfactory. Complete tests using the ON/OFF mode of operation and automatically turning on and off the AN/VRC-12 transmitter will be conducted in the laboratory and in the field during the next quarter.

4.2.2 TURN ON TIME OF THE AN/VRC-12

Automatic control of the AN/VRC-12 transmitter is desired for automated data transmission systems. If digital data is ready to be transmitted, the AN/VRC-12 must be turned on prior to the actual transmission of the data by the modem through the AN/VRC-12 radio link. The time to turn on the radio set was measured in the laboratory using the system shown in Figure 12. A double-pole switch is used to simultaneously turn on the transmitter and apply a 1000 cps signal through a transistor switch to a counter. The transistor switch, initially in the "on" state, is turned "off" by the operation of the squelch in the receiver. Thus the time (in milliseconds) recorded by the counter is the time for a complete radio link to become operative. The results of this test are shown below for both the pre-production and production models of the AN/VRC-12 available at the time the tests were made. Forty samples were taken on each unit.

	Average turn on time	Longest turn on time
Pre-production model	72.2 ms	86.0 ms
Production model	39.6 ms	66.0 ms

These results show that "turn on" time is not constant in any single unit. For the tests that will be conducted in this program the transmitter control unit for turning on the transmitter will be designed with a 100 ms delay which should perform satisfactorily with the units available. A greater number of AN/VRC-12 sets would have to be tested in order to determine if this 100 ms figure is satisfactory for all units.

4.2.3 FIELD TEST OF AN/VRC-12

Short term tests were conducted over an AN/VRC-12 field test link of approximately two miles. Both continuous and ON/OFF operation at 300, 600, and 1200 bps were conducted and the modems performed satisfactorily under all these tests. No error rate figures were available at the end of this quarter since the tests were conducted on an exploratory nature only. Detailed tests will be conducted in the near future at various distances to determine maximum usable distance and maximum usable speed of transmission over the AN/VRC-12.

4.3 FIELD CABLE TESTS

4.3.1 MODEM PERFORMANCE OVER THE AN/TCC-7 CABLE SYSTEM

A full duplex data link for operation at 1200 bps was set up as depicted in Figure 13. This system was investigated to determine the restrictions, if any, on full duplex operation over the AN/TCC-7. The system consists of two AN/TCC-7 terminals (A & B) and the associated repeaters and cables for a complete 80 mile system. Two Di-Phase modems were employed; one transmitter and one receiver was used at each end of the system. One data link consisted of modem 1 (XMTR) connected to terminal A and modem 2 (RCVR) connected to terminal B. A similar data link was set up from terminal B to A. Two data generators and correlators were set up to check the error rates in each transmission path simultaneously.

The first test conducted over this system was the transmission of data from modem 1 (XMTR) to modem 2 (RCVR). Modem 2 (XMTR) was turned off, thus no data was being transmitted to modem 1 (RCVR). Transmission in the A and B direction was error free as expected but modem 1 (RCVR) did not remain muted. Data was received by modem 1 (RCVR) although no data was being transmitted to that terminal. Further investigation showed that modem 1 (RCVR) was actually receiving the data being transmitted by modem 1 (XMTR) with the only connection between the terminals being the crosstalk existing in the AN/TCC-7 system. The received level of the crosstalk at terminal A was approximately -40 dbm, but the level was sufficient for the modem receiver to operate and receive the data being sent in the opposite direction with an error rate of 5 to 10 bps.

The next test conducted over the full duplex system was with both transmitters muted, thus no data was being transmitted in either direction. The noise level in each direction was measured and found to be -45 to -50 dbm, but this noise level was sufficient to sporadically operate both receivers and each modem receiver produced erroneous data.

Both tests described above show that the modem receivers are too sensitive for satisfactory operation over the AN/TCC-7 system. While it is desirable to have high sensitivity in high loss wire line systems it is not necessary for systems where the received level may be controlled by the system terminals. It is suggested that a sensitivity switch be incorporated in the modems to accommodate levels of -15 dbm to +5 dbm for low loss links or levels of -30 dbm to +5 dbm for high loss links. With this option the modems would satisfactorily operate over systems incorporating noise levels below -15 dbm and also be capable of operating over high loss wire line systems.

Full duplex operation over the system shown in Figure 13 was evaluated and error free transmission was conducted in both directions simultaneously. Options in the AN/TCC-7 terminal allow the operator to measure the channel levels. While data is being transmitted on a particular channel, that channel should not be put in the measure mode or in the talk mode because either of these operations will cause errors in transmission. While placing the terminal switch in the monitor position did not cause errors in the laboratory tests, it is recommended that once a channel is designed for digital data transmission all operators in the net should be given instructions to refrain from monitoring that channel. If it is absolutely necessary to monitor a channel, it should be done with the headset and the terminal switch in the monitor position.

4.3.2 MODEM PERFORMANCE OVER TEN TANDEM CHANNELS

A comparison in performance was made between the Di-Phase, Quad-Phase and FSK (AN/TCC-1 XC-2) modems operating over ten tandem channels of the AN/TCC-7 cable system. Equalization was used in the FSK modem, but the other modems did not require equalization to operate at 1200 bps over ten tandem channels. The S/N requirement for each modem was determined for an error rate of 4×10^{-4}. The results are shown in Table 1 and the percent of multiple errors recorded for each test is also given.

Referring to Table 1, note that the noise immunity of the phase modems is better than the FSK modem. It should also be noted that while in the back-to-back mode the performance of the Di-Phase system should theoretically be better than the Quad-Phase modem, the opposite is true for this test. This result may be attributed to the greater bandwidth requirement of the Di-Phase modem since the Quad-Phase modem is less affected by the severe delay characteristics of ten tandem channels (Figure 25 of Quarterly Report No. 2). Although the internal delay equalizer of the FSK modem was used it obviously did not equalize properly and thus contributed to the relatively poor performance of the modem. Equalization was accomplished by observing an oscilloscope for the best integration pattern in the receiver detector.

Table 1 also shows that the FSK modem yielded the least multiple errors. However, since the Di-Phase modem is a coherent system and the Quad-Phase modem is differentially coherent it was expected that the Quad-Phase modem would make a greater percent of multiple errors. The results definitely show that the opposite is true. This was also observed in the white noise tests conducted although no exact figures were obtained. Further studies of the detection scheme employed by the Di-Phase modem will have to be made before any definite reason can be given for this high percentage of multiple errors.

4.3.3 FIELD TEST RESULTS

The tests performed earlier in the program were conducted over a poor AN/TCC-7 system. Although it could be used as a talking circuit for short periods of time, the gain of the system would drop after a few hours of operation preventing long term tests over the system. The results over six tandem channels show that an error rate of approximately 10^{-6} was present for both the AN/TYC-1 and Di-Phase modems. Again a higher percentage of multiple errors was recorded for the Di-Phase modem.

During the month of October the cable system and terminals were completely checked and all marginal tubes were replaced. After the system was repaired the performance of each modem was greatly improved and operation over 10 tandem channels was possible. The latest results are shown in Table 2 as recorded during the months of November and December. All tests were conducted over an 80 mile cable system consisting of two AN/TCC-7 terminals, one AN/TCC-8 repeater, and 12 AN/TCC-11 repeaters connected by spiral four cables. The only noise in the system was that inherent in the cable system.

The approximate number of characters in error with more than one bit in error was measured in the cable field tests and the results are also shown in Table 2 as the "Percent of Characters in Error With More Than One Bit in Error". It should be noted that multiple errors in all modems are almost non-existent with transmission of error rates in the range of 10^{-7} and lower. Complete analysis of the cable test will be withheld until the end of the program.

4.4 WHITE NOISE TESTS

This section describes the performance of the Di-Phase and Quad-Phase modems in the presence of white noise. Also the degradation in performance of the Quad-Phase modem due to AN/TCC-7 tandem channel operation is given.

4.4.1 MODEM BACK-TO-BACK TESTS

White noise tests were performed with the Di-Phase modem operating at 150, 300, 600 and 1200 bps; the results are shown in Figure 14. As shown in the results, the difference in performance between 1200 bps and 600 bps is approximately four db, while the difference between 600 bps and 300 bps is only about one db, and there is very little difference in performance between 300 bps and 150 bps. Theoretically the performance should improve by three db when the bit rate is reduced by a factor of one-half, therefore, these results indicate that the modem performs best at the 600 bps rate, and there is very little advantage in reducing the bit rate from 300 to 150 bps or even reducing the rate from 600 to 150 bps. The modem performance in the presence of impulse noise may show a different relationship between bit rates. This will be investigated in the near future. The modem performance in Figure 14 is slightly different than shown in Figure 1 of the Fourth Quarterly Report since a second modem was tested during this last quarter and found to be a little better than the first modem in back-to-back performance without noise. This unit is enclosed in a case, and noise in the laboratory does not cause errors within the modem.

Performance of the Quad-Phase modem in the presence of white noise is shown in Figures 15 and 16 for two different tests. In the first test the carrier frequency was 1650 cps while in the second test the carrier was changed to 1920 cps to extend the modem's performance over the AN/TCC-7 as explained in the Fourth Quarterly Report. In the second test the filter in the receiver portion of the modem was removed since it was designed for a carrier frequency of 1650 cps.

The results in Figure 15 show that the modem performs better at 1200 bps than at 600 or 2400 bps. These results are not readily explained and it even becomes more complicated when the results in Figure 16 are studied where the 600 bps rate shows the best performance. Leaving the filter out and changing the carrier frequency back to 1650 cps results approximately in the same performance shown in Figure 16, thus the change is not due to the carrier shift. It is believed that the filter characteristics affect the timing recovery and change the modem performance.

4.4.2 MODEM OPERATION OVER THE AN/TCC-7 IN THE PRESENCE OF WHITE NOISE

The degradation of modem performance due to tandem channels of the AN/TCC-7 was determined by conducting the white noise tests with the modem operating over the AN/TCC-7. Figures 17, 18, and 19 show the tandem channel operation of the Quad-Phase modem at 600, 1200, and 2400 bps. These results were obtained with a carrier frequency of 1650 cps and the bandpass filter in the receiver. At 600 bps an improvement is realized as the modem operates over tandem channels of the AN/TCC-7. A degradation is noted at 1200 bps but the degradation is only about 4 db for operation over 12 tandem channels. An interesting result is shown in Figure 19 for the modem operation at 2400 bps. Two curves are shown for the modem operating back-to-back in the presence of white noise. The first is the same curve shown in Figure 15 and the second curve is the result of operating the modem back-to-back with equalization. The improvement in performance is approximately 6 db. This back-to-back curve approaches the performance of the modem at 2400 bps without the bandpass filter. A comparison of Figures 16 and 19 shows that there is less than a 1/2 db difference between the curves; this could be the result of having a delay characteristic that is equalized by the internal equalizer resulting in better performance at 2400 bps. However, further study of the filter characteristics and the modem operation is necessary before any definite conclusion can be made.

4.5 DATA GENERATOR AND CORRELATOR

4.5.1 CHARACTERISTICS OF NEW GENERATOR AND CORRELATOR

A new digital data generator and correlator has been designed and constructed employing many features not available in our present system. The main consideration in designing the new system was to be able to operate the data generator and correlator from completely different sites so that mobile tests of the modems would be possible. In order to accomplish this a pseudo-random pattern generation technique was chosen employing a recirculating generator as the data source. A more detailed design description is given in paragraph 4.5.2.

The system is capable of generating and correlating a pseudo-random pattern of 2047 bite in length and also any eight bit fixed pattern which may be selected on the control panel of each unit. The data generator and its power supply is completely separate from the correlator and is designed as a portable unit. The new data generator with its power supply is shown in Figure 20.

Data may be presented to the modem in serial or parallel form with the parallel form meeting the specifications of the Army Fieldata format. Also available is continuous data transmission or the ON/OFF mode of operation through the use of the ready-strobe in the parallel mode. In this mode a message of a set length (1 to 256 characters) is transmitted and then data transmission is inhibited for a time set by the operator (0.1 to 5 seconds). Bit rates up to 600,000 bps are possible in both the serial and parallel modes.

4.5.2 BLOCK DIAGRAM DESCRIPTION

Figure 21 shows this data generator in block diagram form. The data is generated in the 11 stage shift register (SR-1 through SR-11) with feedback from SR-9 and SR-11 through the "Exclusive OR" circuit. This generates a pseudo random pattern with a length at 2047 bits. In the fixed pattern mode only stages SR-1 through SR-8 of the shift register are used and the initial state of this register is set by selecting the 8-bit pattern desired and then pushing the pre-set button. This sets the eight stages to the desired state while simultaneously inhibiting the shift pulses to the register.

The shift pulses are generated by the clock circuits consisting of a flip-flop, an astable multivibrator and count down circuits. In the serial mode, one shift pulse is generated for each bit time of the modem. In the parallel mode eight shift pulses are generated for each ready signal received from the modem. When either a bit timing signal or ready signal is received, the 8-stage buffer is loaded with the information in the shift register and then the shift pulses are generated to set the shift register with a new character. The output converters apply the proper levels to the modems for the eight data lines and the strobe. The strobe is generated as the buffer is loaded. The bit timing or ready signal is applied to a schmitt trigger circuit which generates a pulse compatible with the high speed logic circuits.

In the ON/OFF mode of operation the ready signal from the modem is inhibited while FF-2 is in the "reset" condition. A variable frequency multivibrator (MV clock) "sets" the flip-flop (FF-2) which then allows the ready signal to initiate normal action in the data generator. When the output of the BC-3 counter (1 to 256 count) applies a positive step to FF-2 the ready signal is inhibited and the procedure is again repeated.

The data correlator shown in Figure 22, operates in a similar manner as the generator. An 11-stage register generates the same pseudo-random pattern and this pattern is compared with the data received from modem. Synchronization of the correlator with the incoming data is accomplished by feeding the data into the last three stages of the register, thus "setting" the register with the same pattern as the incoming data. When errors are no longer detected the synch switch is placed into the normal position and error detection takes place by comparing each data bit stored in the buffer with the information in the eighth stage (SR-8) of the register.

Parallel data is fed into the correlator through the input converters and gated into the 8-stage shift register (B). In the serial mode each bit is fed into the first shift register (A) which is then gated into the second register (B) after eight data bits. The loading and shifting pulses are generated from the ready or bit timing signals as shown in the block diagram. After the data is loaded into the B-register it is then compared with the generated data in the recirculating generator. The error pulses are sent to the logging circuits in bursts at the internal clock rate of 900 kc. A "character frame" pulse is generated at the end of the error burst informing the logging circuits that the end of an error burst has occurred and the analysis of the errors may take place.

The data generator and correlator has been checked back-to-back and no errors were generated by the system in a 24 hour test. Also, a known number of errors were introduced in the transmitted data and detection in the correlator was 100 per-cent. Representative white noise tests on the modems were conducted using the new system and the results compared almost exactly with the results obtained with the old correlator.

4.6 AN/TRC-24 FIELD TESTS

The test of the AN/TRC-24 field system described in the Fourth Quarterly Report have not been entirely satisfactory. All the modems operate over the system with error rates less than 10^{-7}, for a transmitter power level of 8 watts (the low power position of the AN/TRC-24). Aside from the fact that the AN/TRC-24 seems to present no basic obstacle to digital data transmission in either the FSK or PSK modulation form, no significant data for error statistics has been obtained. Often a modem will perform error free at 1200 bps for 10 or 15 hours.

Since the AN/TRC-24 radio set is designed for distances of 30 to 40 miles, the radio link of 2 miles, even at low power, does not present a typical military communications link. Possibly a link of 8 to 10 miles operating at low power would result in a more significant error pattern that could be analyzed statistically. At this time the only conclusion that can be drawn is that the AN/TRC-24 seems to present no problem in digital data transmission.

SECTION V

CONCLUSIONS

Back-to-back white noise tests of the Di-Phase modem at the various bit rates show that there is little advantage in lowering the bit rate of this modem below 300 bps. This modem was primarily designed for higher bit rates and at the lower bit rates it does not perform near its theoretical limits. It appears that the only situation in which the lower bit rate would be utilized would be for matching bit rates in systems not capable of operating at rates in excess of 150 bps. These lower rates obviously do not make good use of the channel capacity available for data transmission in the AN/TCC-7 and AN/VRC-12.

The comparison of modem performance over ten tandem channels of the AN/TCC-7 at 1200 bps yielded very interesting results. The tests of Di-Phase and Quad-Phase modems in the back-to-back mode indicated that the Di-Phase modem exhibited superior performance in the presence of white noise. However, when operating the two modems over the AN/TCC-7 tandem channels again with white noise, but without equalization, the Quad-Phase modem performed slightly better. This change in relative performance can be directly attributed to the smaller spectrum required by the Quad-Phase modem and the signal is less affected by the delay distortion introduced by the AN/TCC-7. If the channel was carefully equalized, it is expected that the relative results would not change by introduction of the AN/TCC-7 delay characteristics. The AN/TYC-1 (XC-2) with equalization performed much worse than either of the phase modems. The spectrum required by FSK modems is much greater than either of the phase modulation schemes, thus very good delay equalization would be necessary before the performance of this modem would approach that of the other modems while operating over 10 tandem channels of the AN/TCC-7. Proper equalization of the AN/TYC-1 is difficult to achieve, and it is believed that equalization to the degree required cannot reasonably be expected under field conditions. It is recommended that, if at all possible, the field personnel should not attempt to equalize a channel unless equipment is available to check the error rate of the modem or the equalization effect accurately.

Preliminary tests of the modems operating over the AN/VRC-12 radio set have been very satisfactory. Bit rates up to 1200 bps have presented no operational problems on the short range tests of two miles from a fixed station.

SECTION VI

PROGRAM FOR NEXT INTERVAL

Completion of the error logging circuits is scheduled for the next quarter. The automated data recording system will be completed during the quarter if the paper tape punch is received.

The Transmitter Control Unit for automatically controlling the AN/VRC-12 will be designed and constructed. This system will be used to investigate the operation of the AN/VRC-12 in an automatically controlled data processing system. Both laboratory and field tests will be conducted in this phase. Fixed station field tests of the AN/TYC-1, Di-Phase, and Quad-Phase modems operating over the AN/VRC-12 will be conducted. Error rates will be obtained for the various bit rates of each modem.

SECTION VII

IDENTIFICATION OF KEY PERSONNEL

Dr. J. Cohn	Chief Engineer
W. Borman	Assistant Chief Engineer
J. Tsimbidis	Project Engineer
R. Salava	Development Engineer
J. Gabalis	Development Engineer

Summary of Man-Hours

	11 Sept 1962 to 10 Dec 1962	Total To Date
J. Tsimbidis	111	734
R. Salava	472	1634
J. Gabalis	-	1088
W. Smith	-	32
E. Kandora	-	5
J. Nicolini	-	24

TABLE 1

TANDEM CHANNEL PERFORMANCE OF MODEMS

Modem	S/N (db) requirement	Per cent of multiple errors
Quad-Phase	8	1.7
Di-Phase	11	21.1
FSK (AN/TYC-1)	20	0

TABLE 2

	Date	Modem	Bit Rate (bps)	Tandem Channels	Total Test Time (Seconds)	Error Rate	% Characters In Error With More Than One Bit In Error	Hits	Drop Outs	Note
1	9-12-62	Di-Phase	1200	6	8,000	5.8×10^{-6}		0	0	1
2	9-13-62	Di-Phase	1200	6	38,000	1.1×10^{-6}	60.5	0	0	1
3	9-13-62	Di-Phase	1200	6	11,000	9.5×10^{-6}	50.0	0	0	1
4	9-18-62	AN/TYC-1	1200	6	26,000	1.41×10^{-6}	12.4	0	0	1 & 4
5	11-14-62	Quad-Phase	1200	10	87,000	5.94×10^{-7}	22.0	0	0	
6	11-15-62	Quad-Phase	1200	8	96,000	4.16×10^{-8}	0	0	0	
7	11-23-62	Quad-Phase	2400	8	157,000	1.2×10^{-7}	-	0	0	2
8	11-28-62	Quad-Phase	1200	10	65,000	1.3×10^{-8}	0	0	0	
9	12-3-62	Di-Phase	1200	10	2,000	4.3×10^{-5}	6.2	0	0	3
10	12-3-62	AN/TYC-1	1200	10	2,000	1.4×10^{-4}	0	0	0	3 & 4
11	12-5-62	Di-Phase	1200	10	56,000	9×10^{-8}	0	0	0	
12	12-5-62	AN/TYC-1	1200	10	17,000	1×10^{-7}	0	0	0	4
13	12-6-62	Quad-Phase	1200	10	58,000		0	0	0	
14	12-7-62	Di-Phase	1200	10	24,000	3.5×10^{-8}	0	0	0	

NOTES:

1. System was functioning improperly. See paragraph 4.3.3.
2. One error burst had 36 bit errors and eleven characters in error.
3. AN/TCC-7 required alignment.
4. Modem equalization was needed.

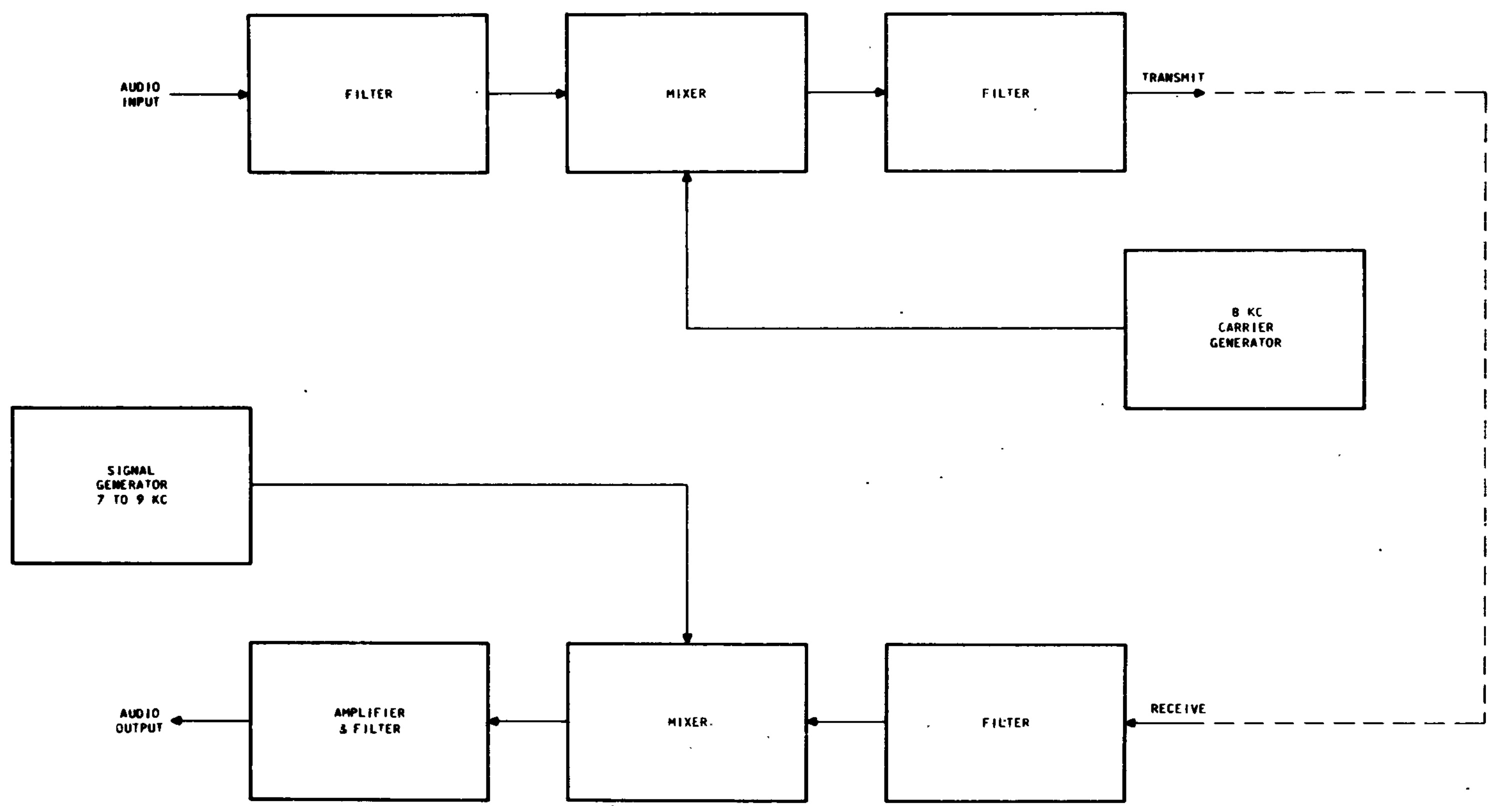


Figure 1. Frequency Translation Test Setup

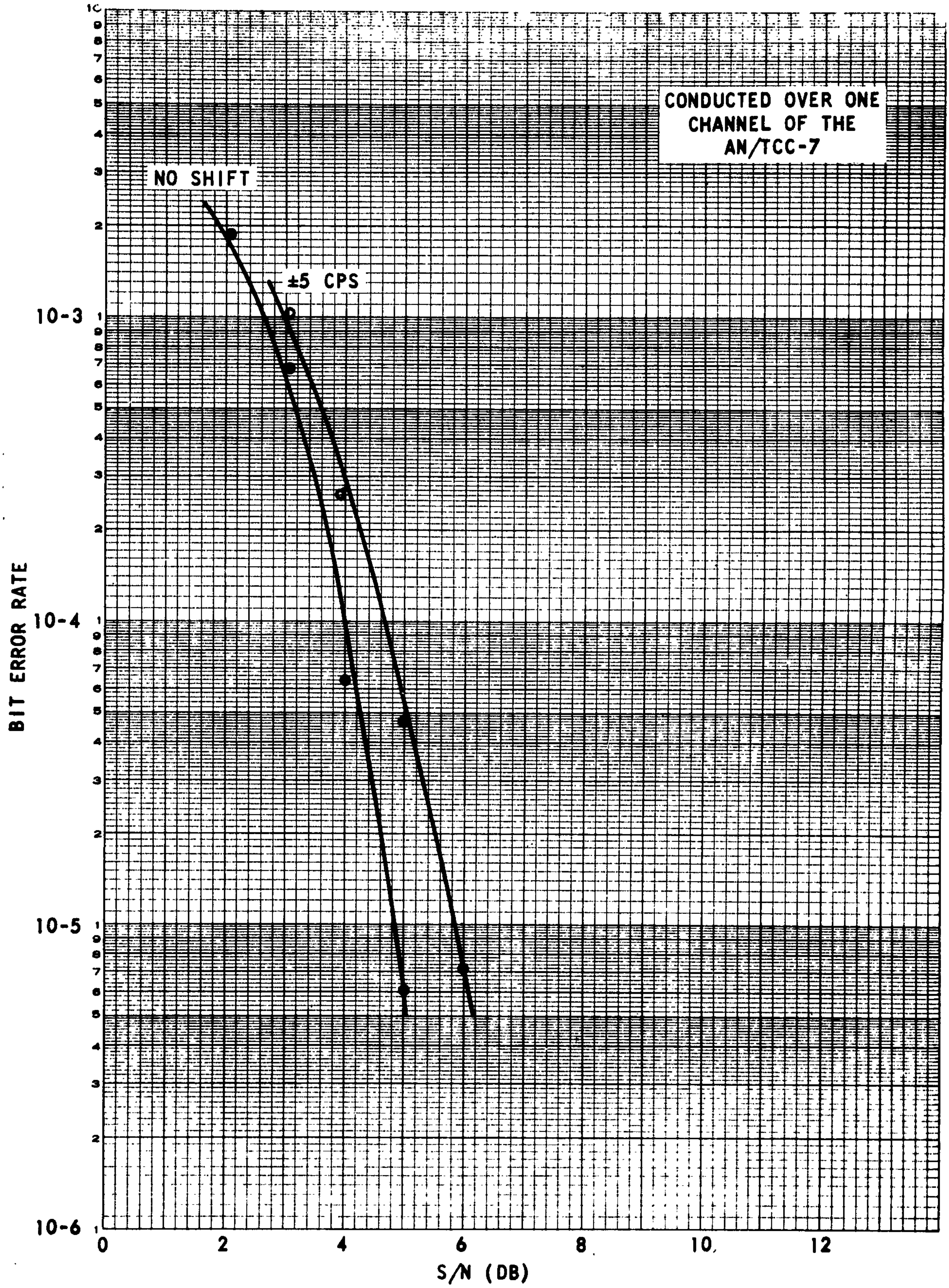


Figure 2. Di-Phase Modem Degradation Due To Frequency Translation, ±5 cps, 600 bps

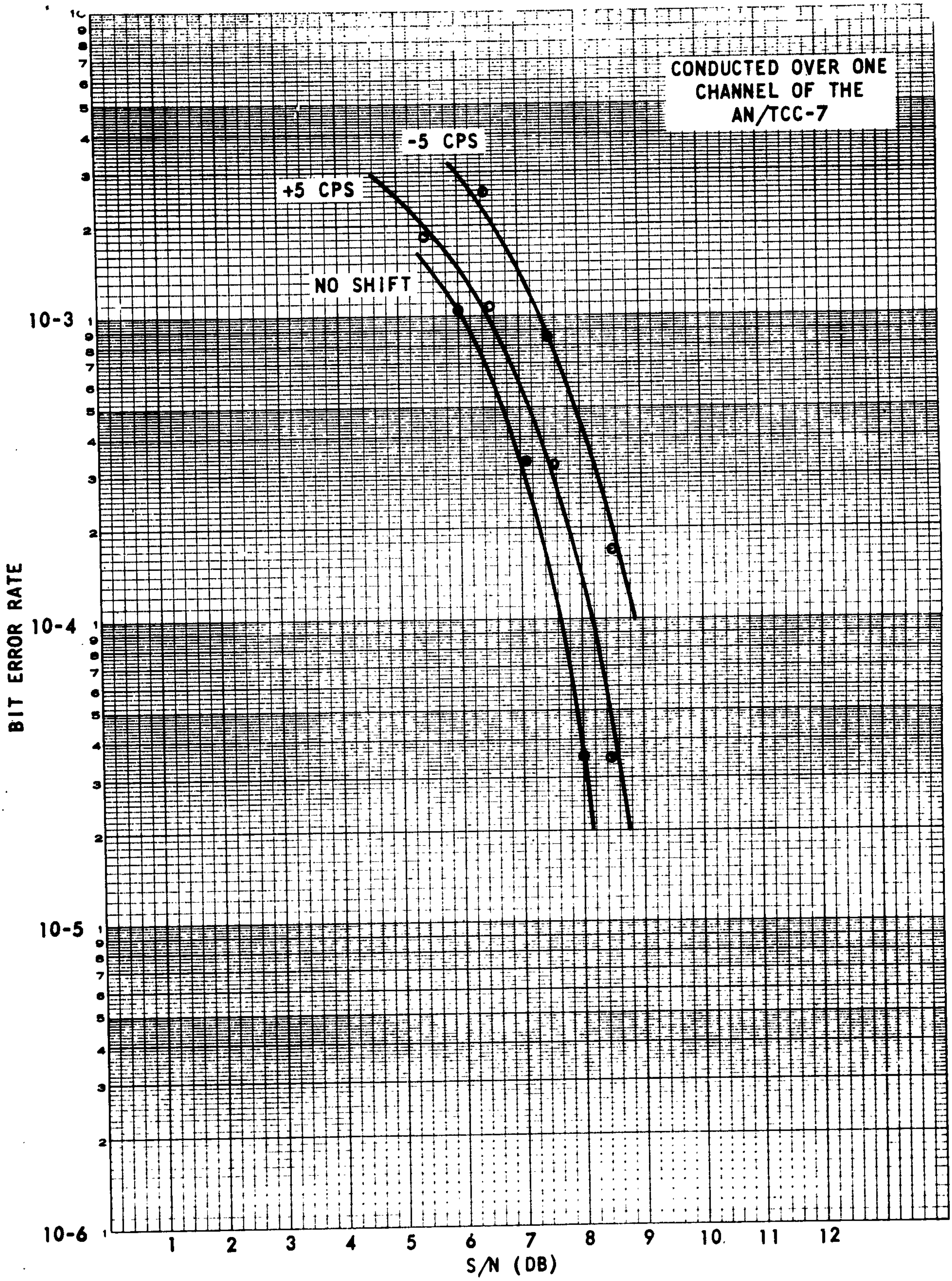


Figure 3. Di-Phase Modem Degradation Due To Frequency Translation, ±5 cps, 1200 bps

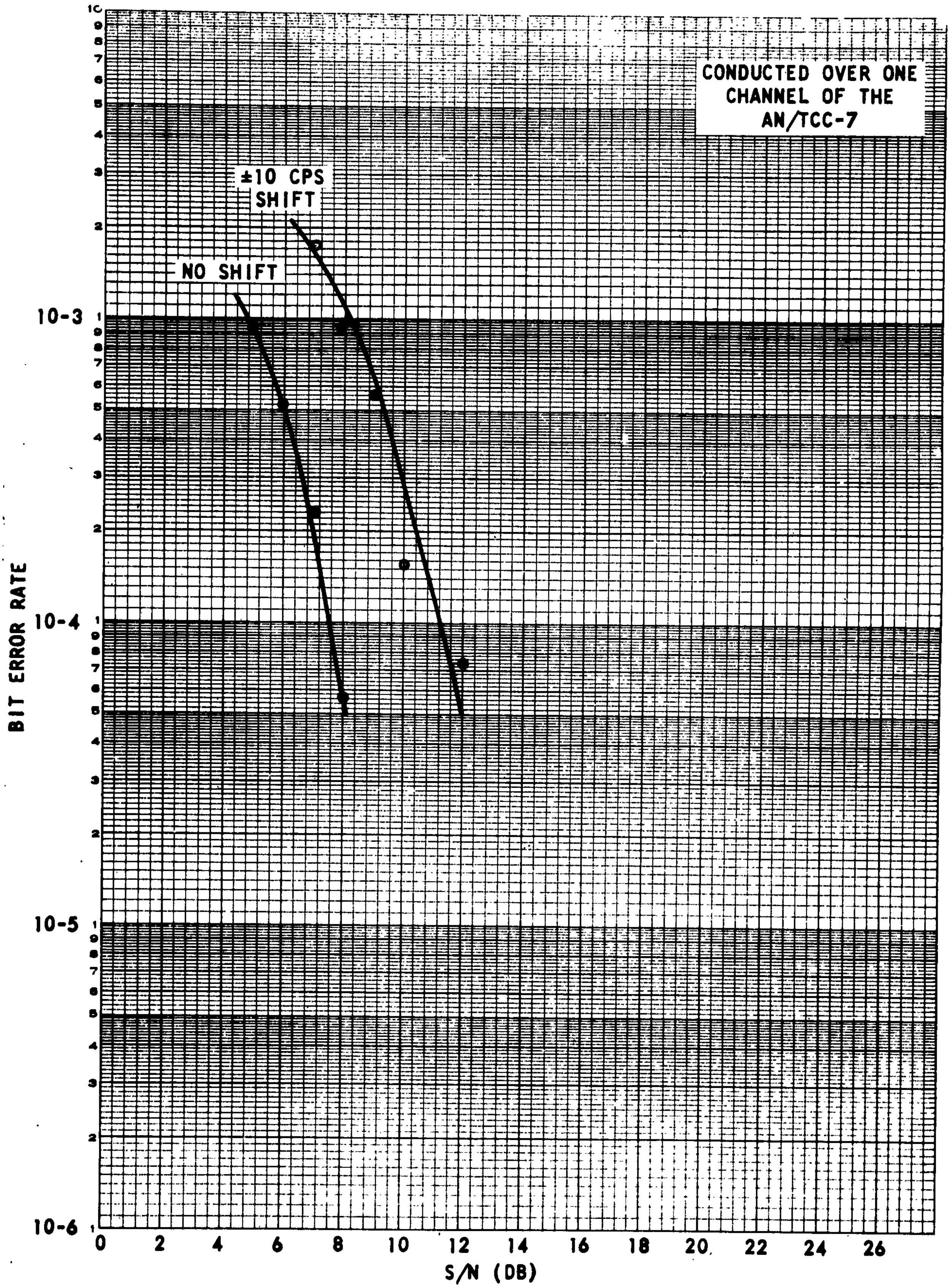


Figure 4. Quad-Phase Modem Degradation Due To Frequency Translation, ±10 cps, 600 bps

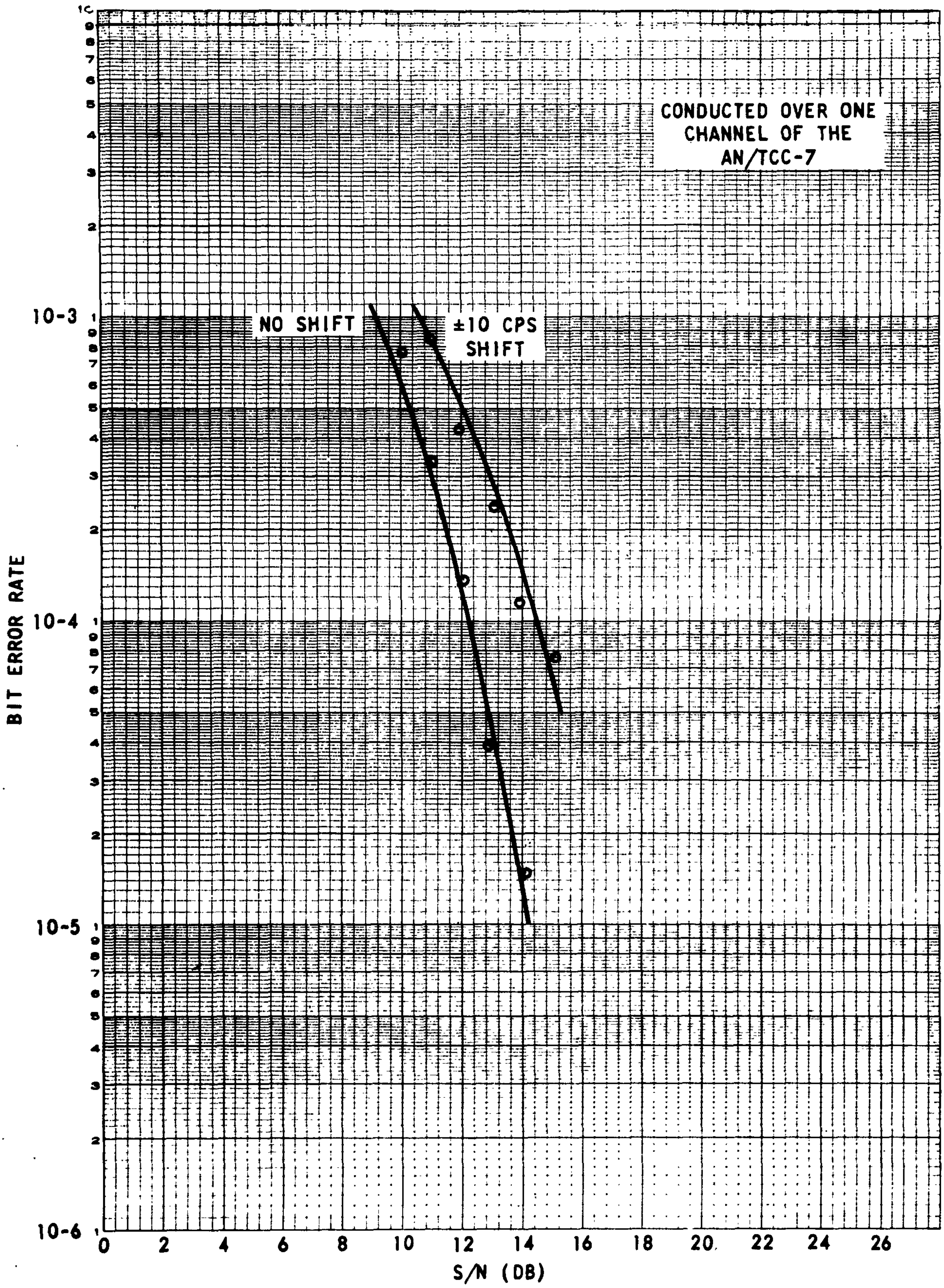


Figure 5. Quad-Phase Modem Degradation Due To Frequency Translation, ±10 cps, 1200 bps

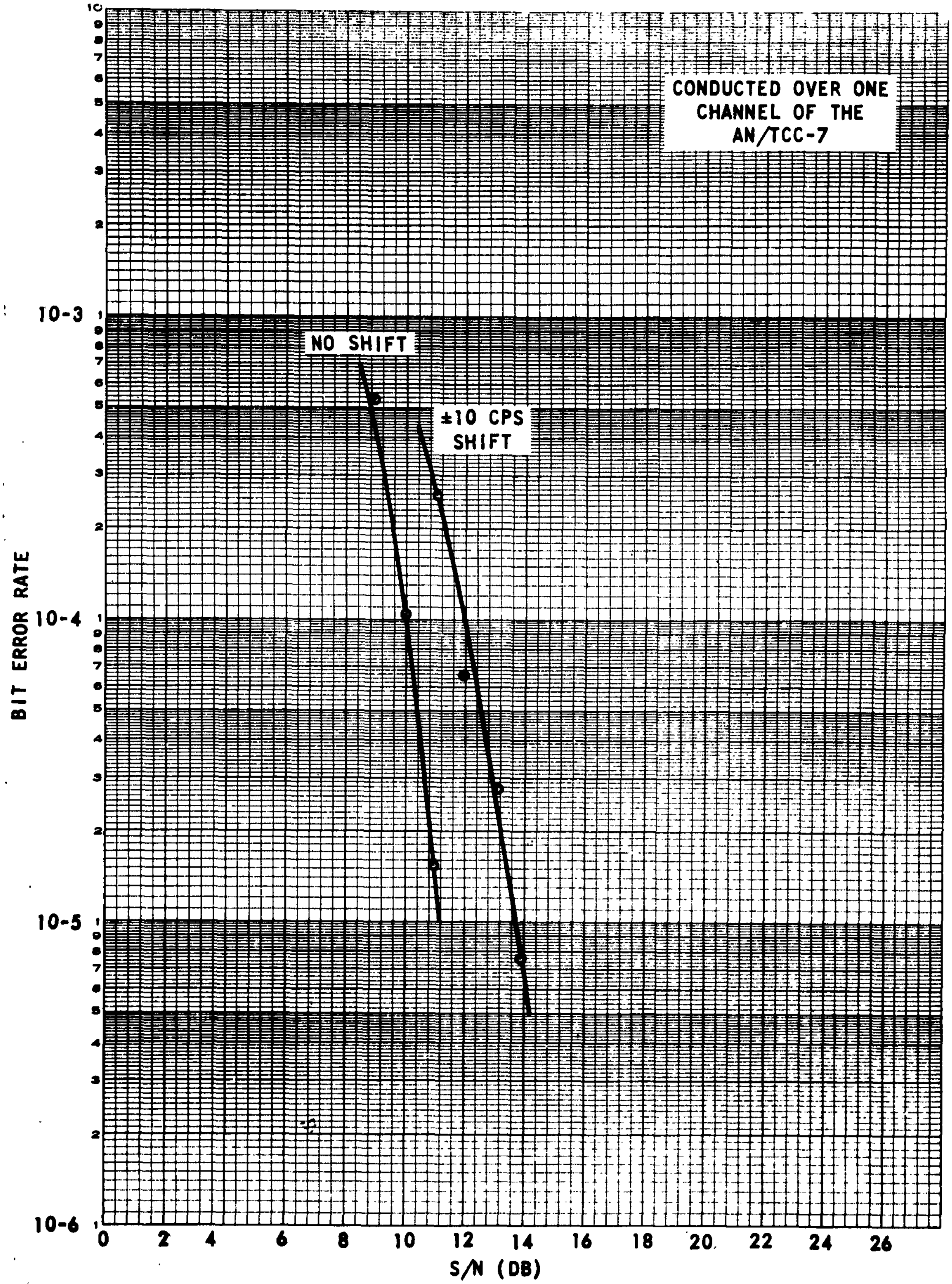


Figure 6. Quad-Phase Modem Degradation Due To Frequency Translation, ±10 cps, 2400 bps

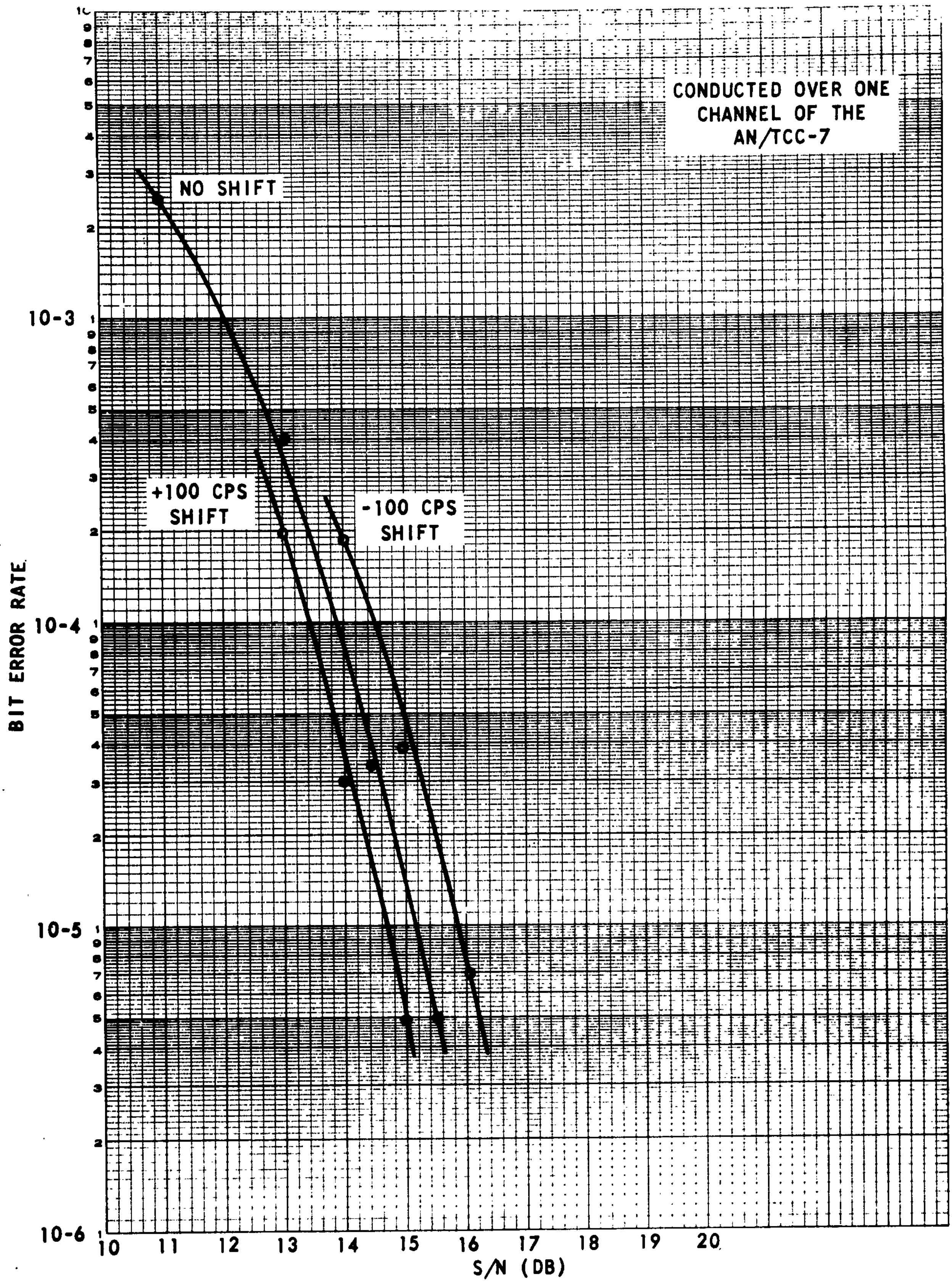


Figure 7. VSB Modem Degradation Due To Frequency Translation, ±100 cps, 2400 bps

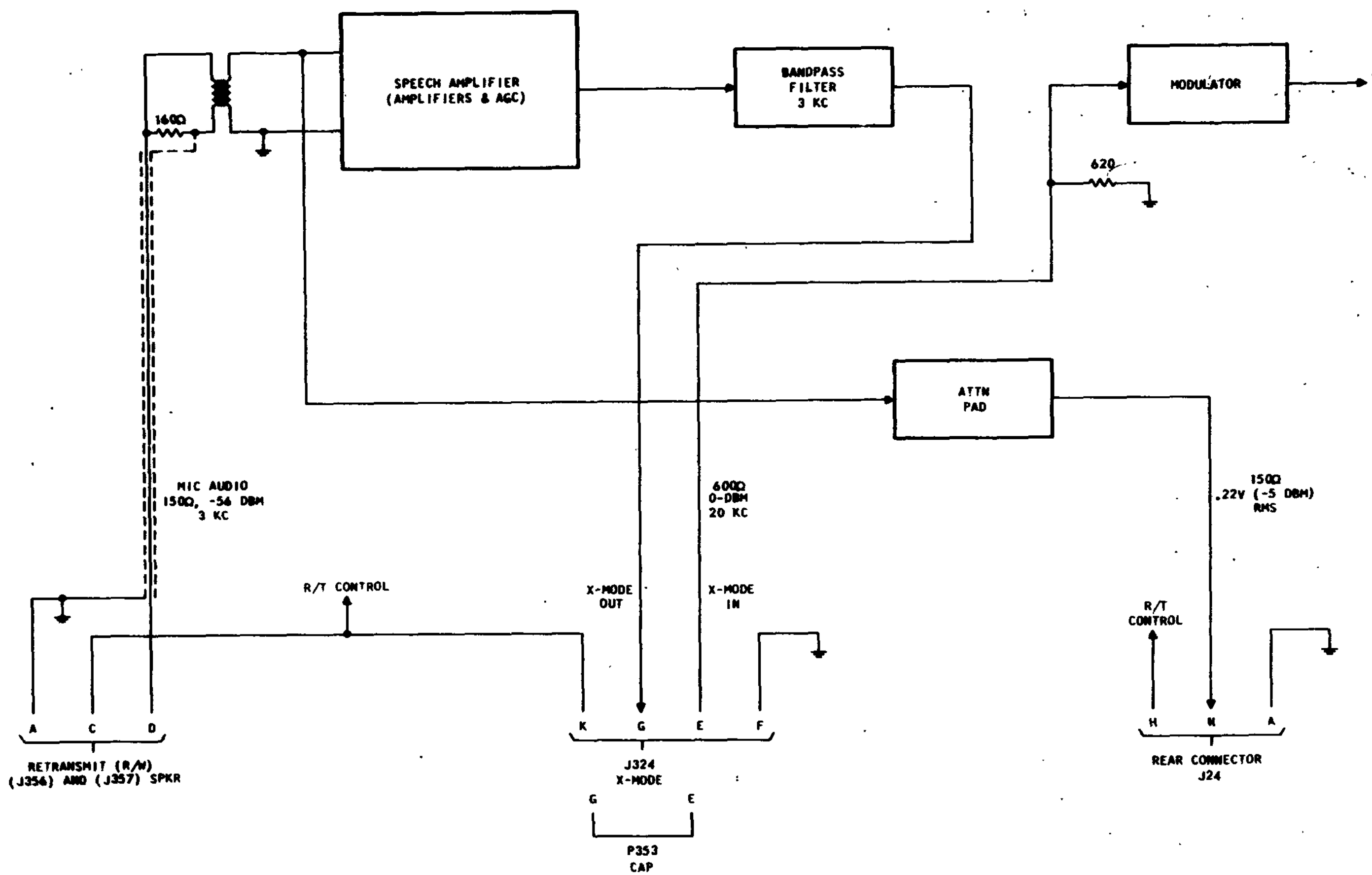


Figure 8. AN/VRC-12 Transmitter Input Connections

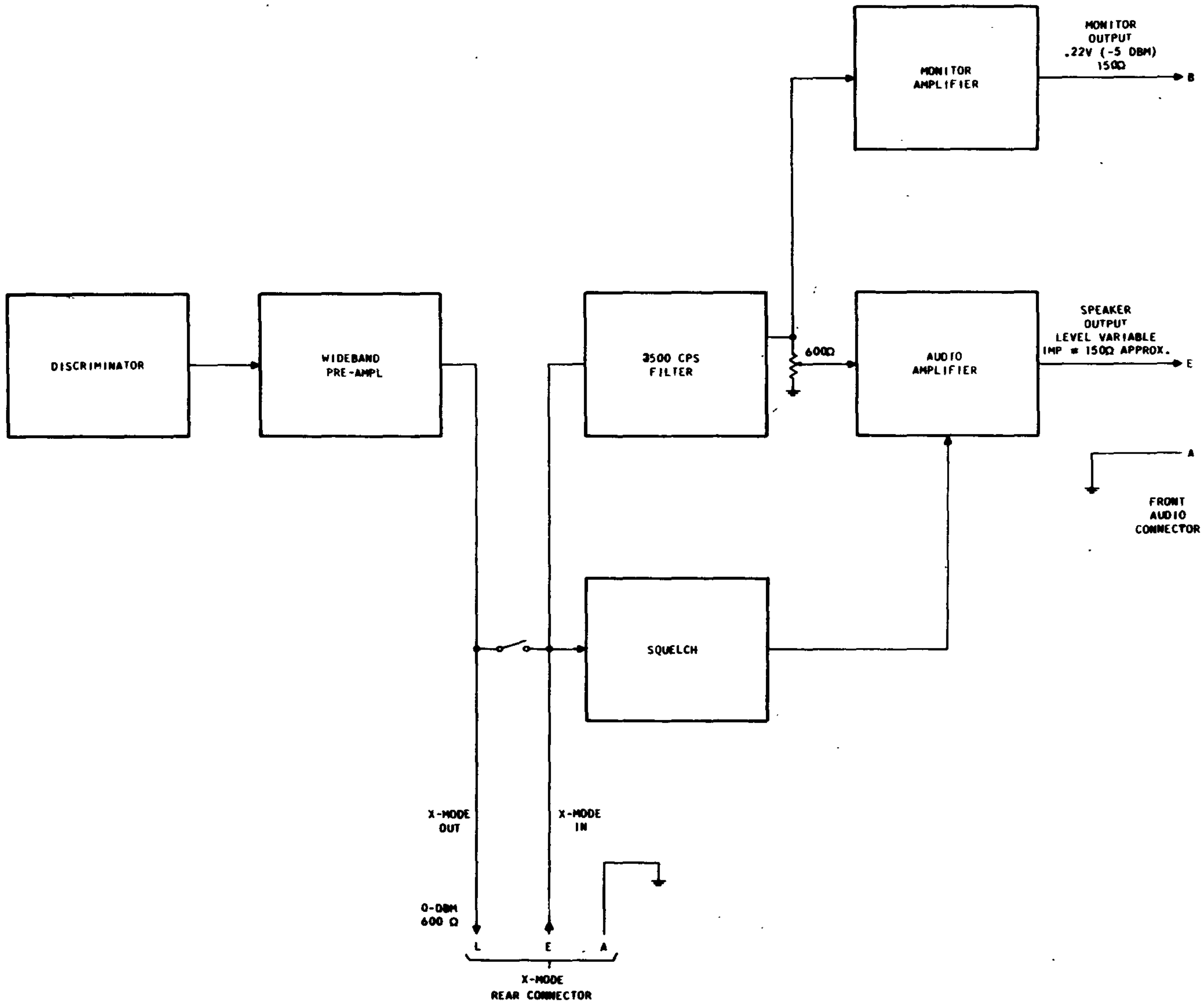


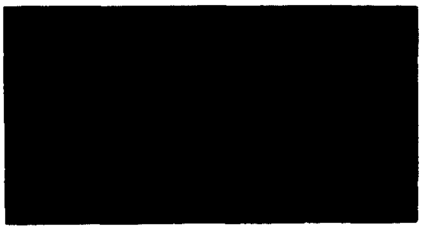
Figure 9. AN/VRC-12 Auxiliary Receiver Output Connections

AN/VRC-12 RCVR OUTPUT
AN/TYC-1 SYNC CHARACTERS
1200 bps

(A)

OUTPUT FOR
MIC-INPUT
(150 Ω)

(B)



OUTPUT FOR
X-MODE INPUT
(600 Ω)

Figure 10. Signal Distortion in Preproduction AN/VRC-12

AN/VRC-12 RCVR OUTPUT
AN/TYC-1 SYNC CHARACTERS
1200 bps

(A)

OUTPUT FOR
MIC-INPUT
(150Ω)
(-50 DBM)

(B)

OUTPUT FOR
MIC-INPUT
(150 Ω)
(-60 DBM)

(C)

OUTPUT FOR
X-MODE INPUT
(600Ω)
(0 DBM)

Figure 11. Signal Distortion in Production AN/VRC-12

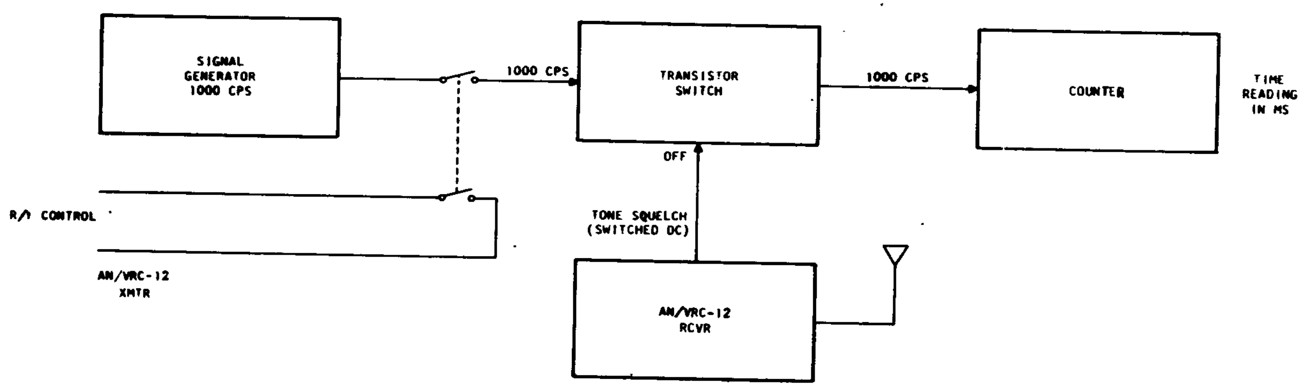


Figure 12. Turn-On Time Measuring Setup For AN/VRC-12

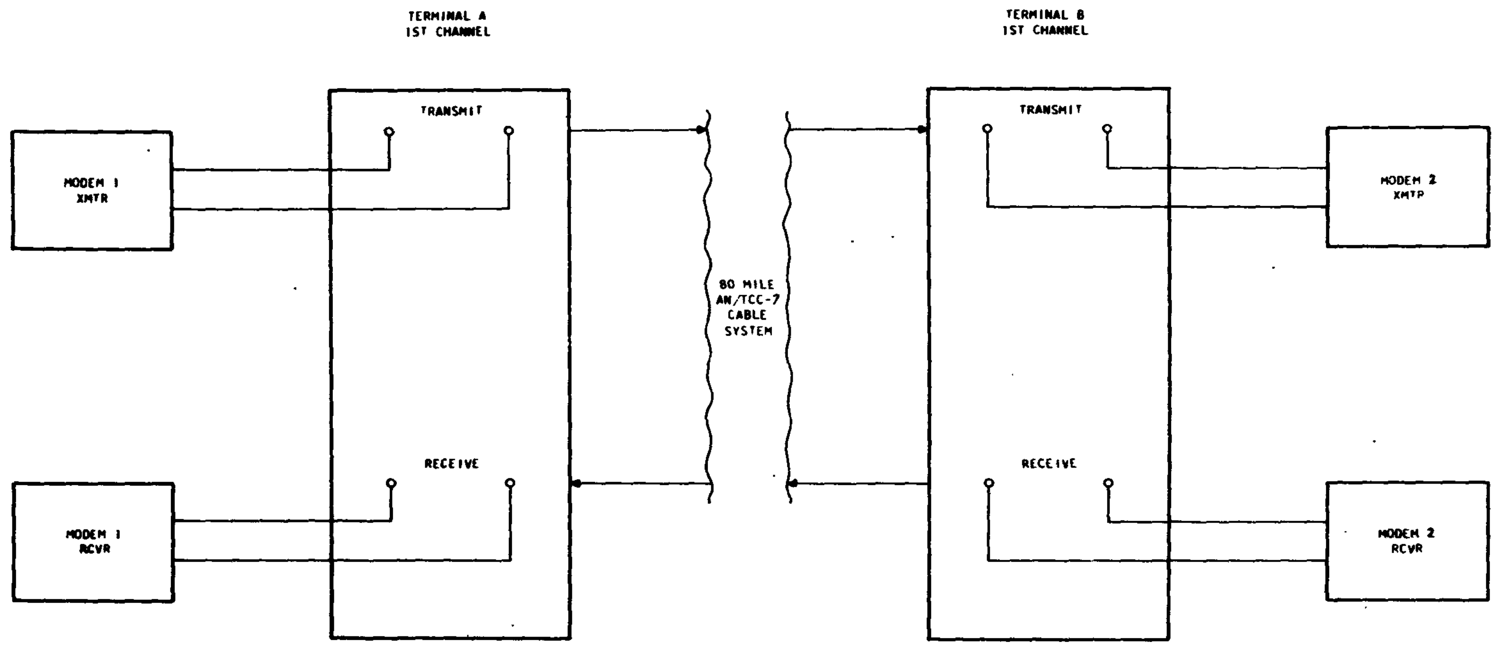


Figure 13. Full Duplex Operation Over AN/TCC-7 Cable System

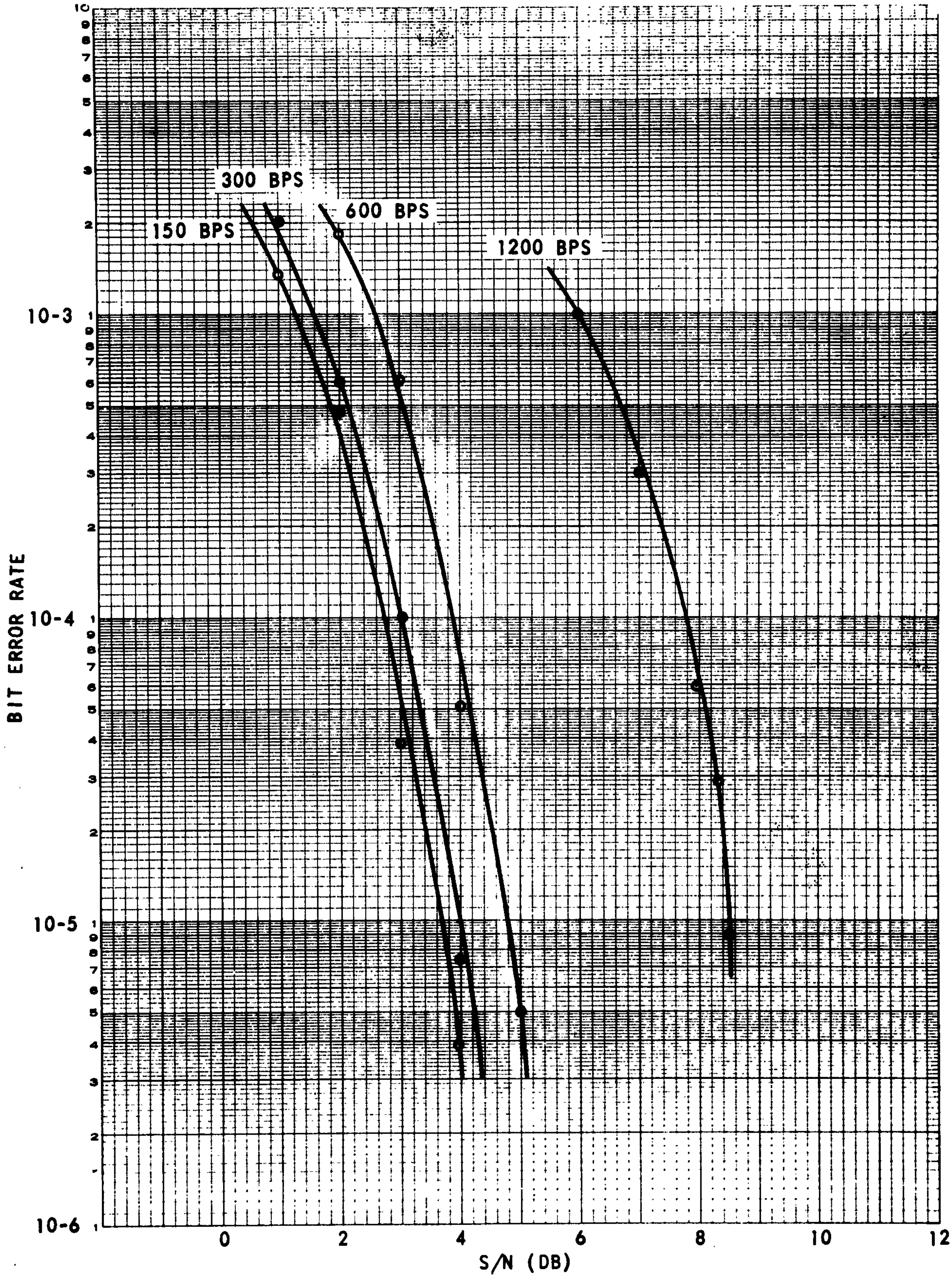


Figure 14. White Noise Performance of Back-to-Back Di-Phase II Modem

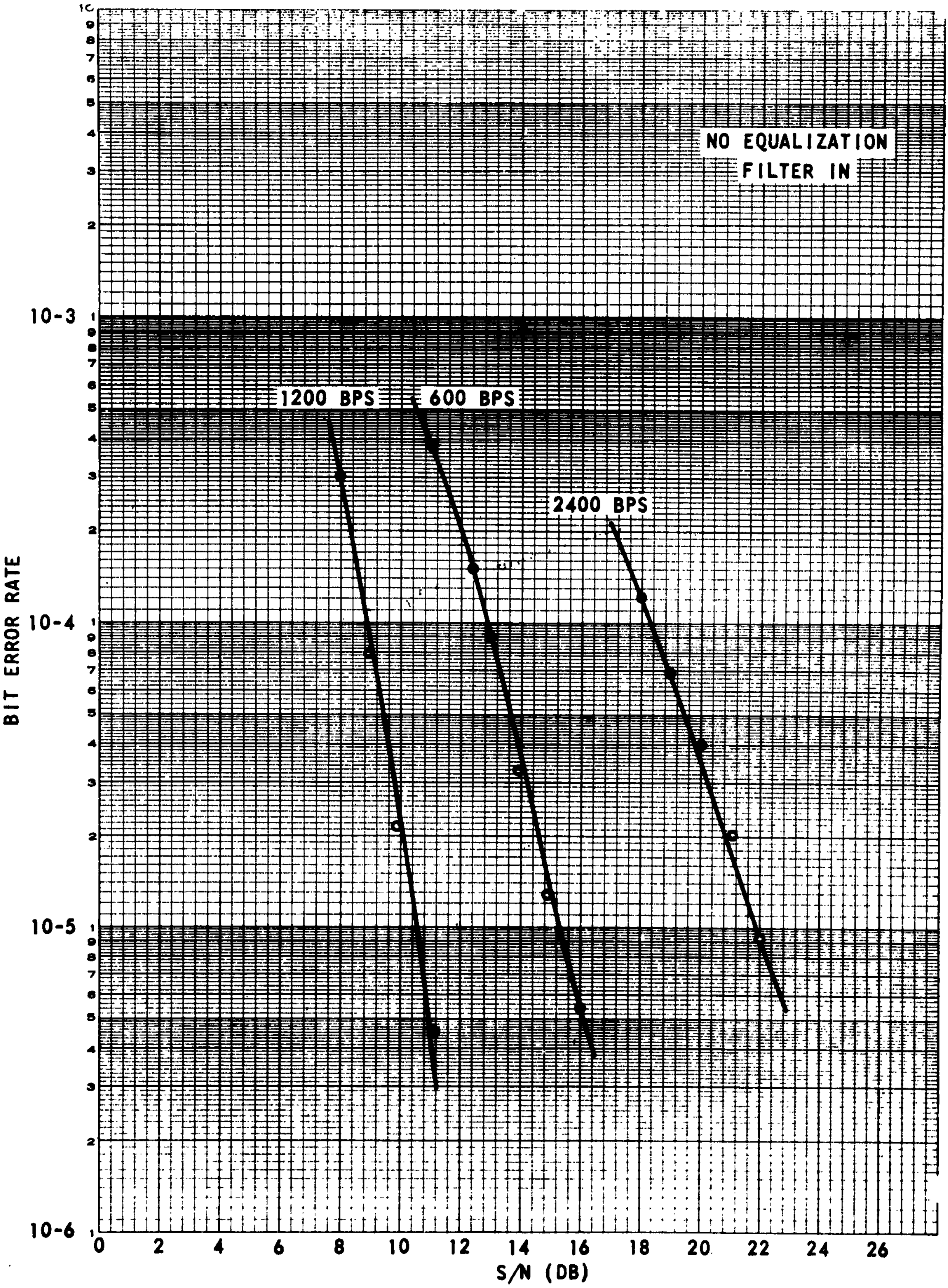


Figure 15. White Noise Performance of Back-to-Back Quad-Phase Modem -- f_c = 1650 cps

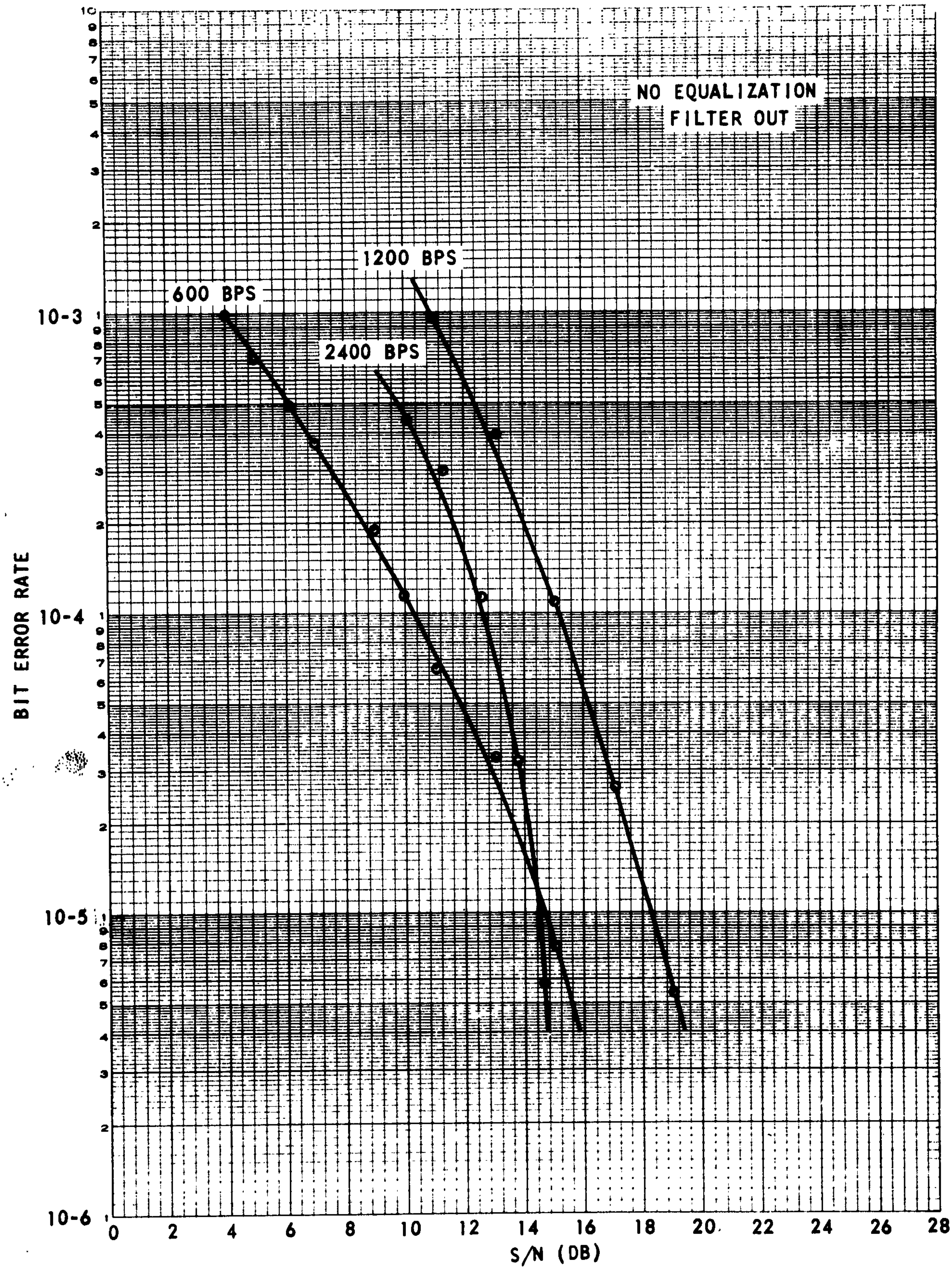


Figure 16. White Noise Performance of Back-to-Back Quad-Phase Modem -- f_c = 1920 cps

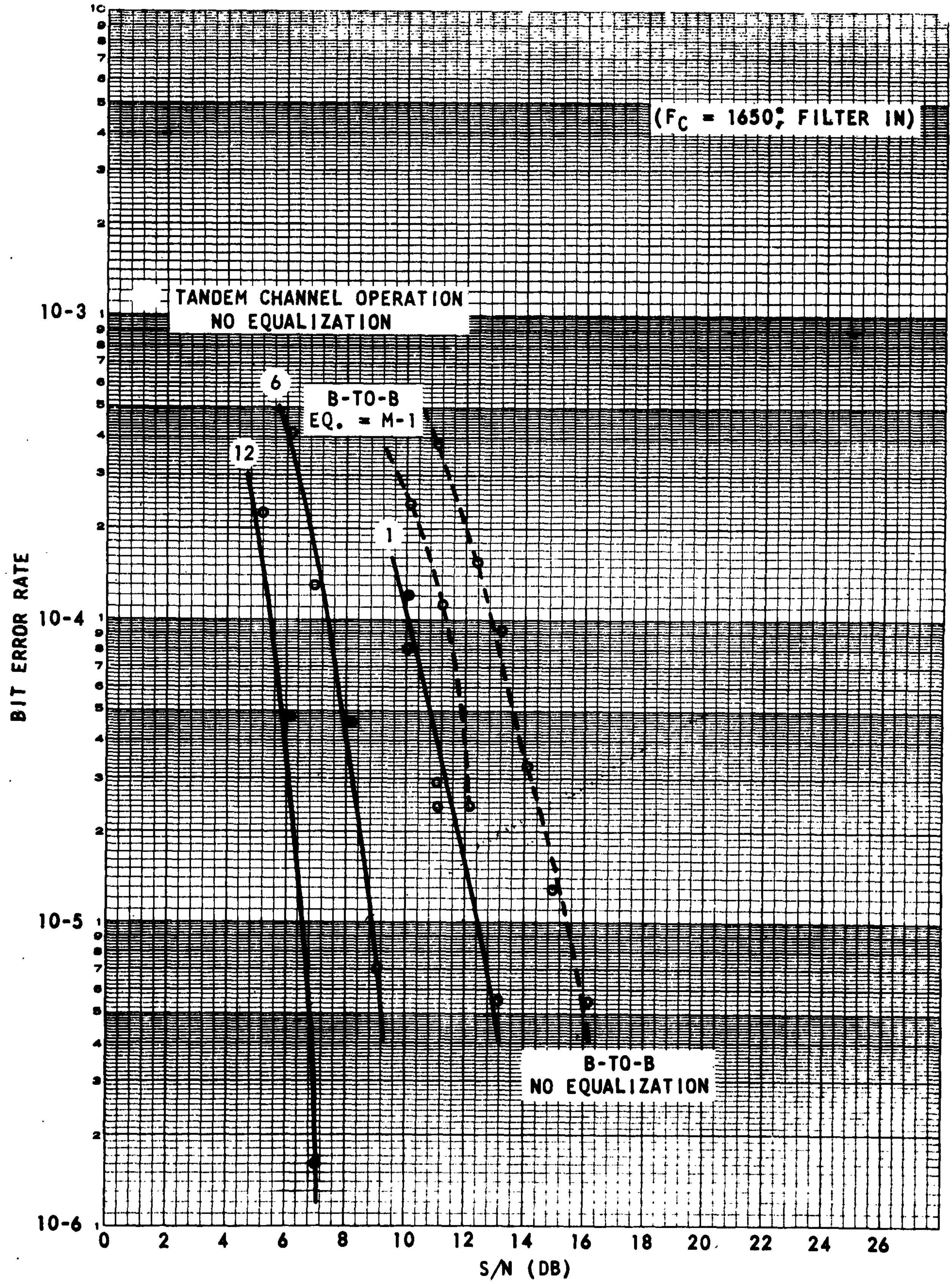


Figure 17. White Noise Performance of Quad-Phase Modem Over AN/TCC-7, 600 bps

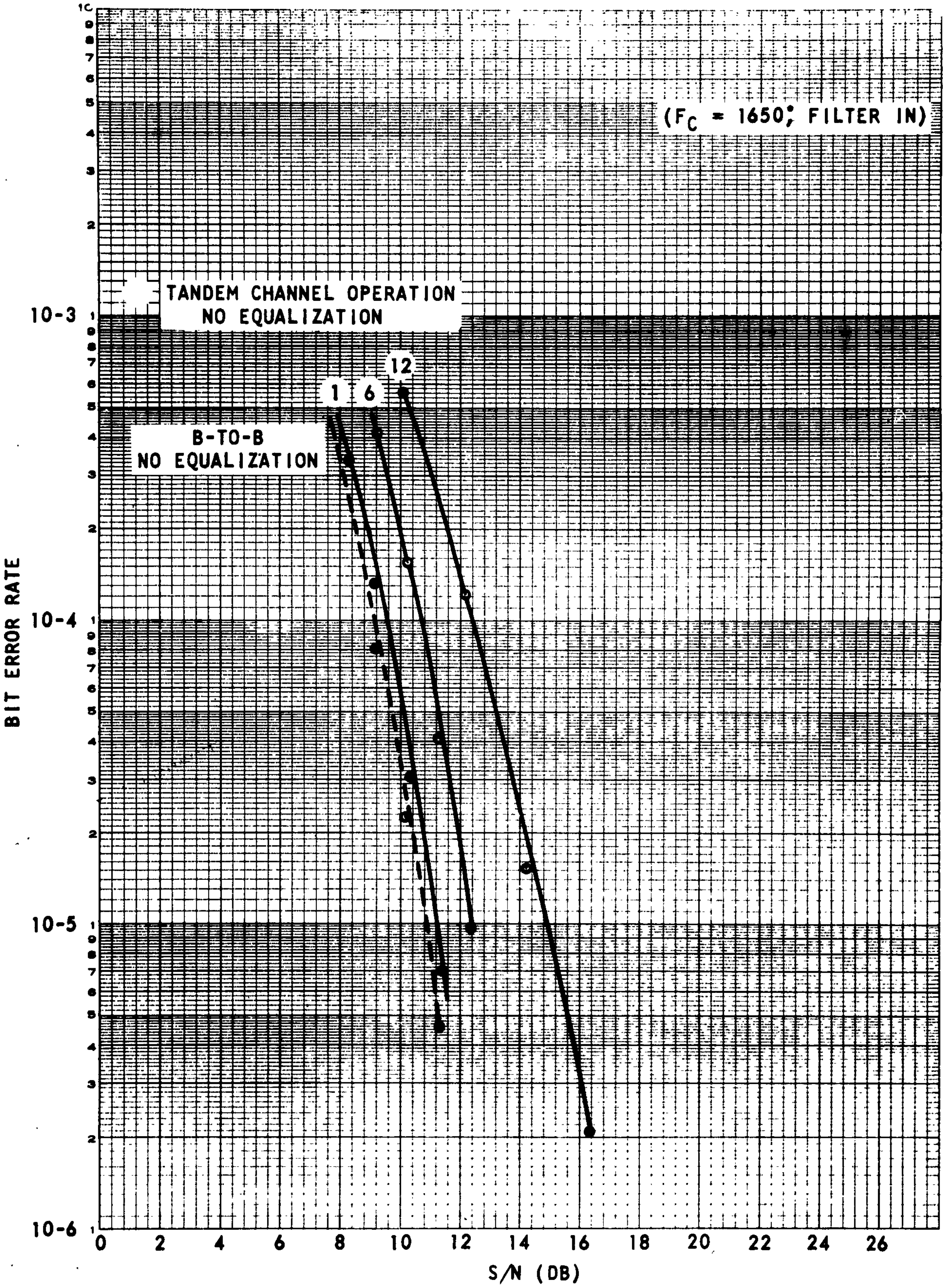


Figure 18. White Noise Performance of Quad-Phase Modem Over AN/TCC-7, 1200 bps

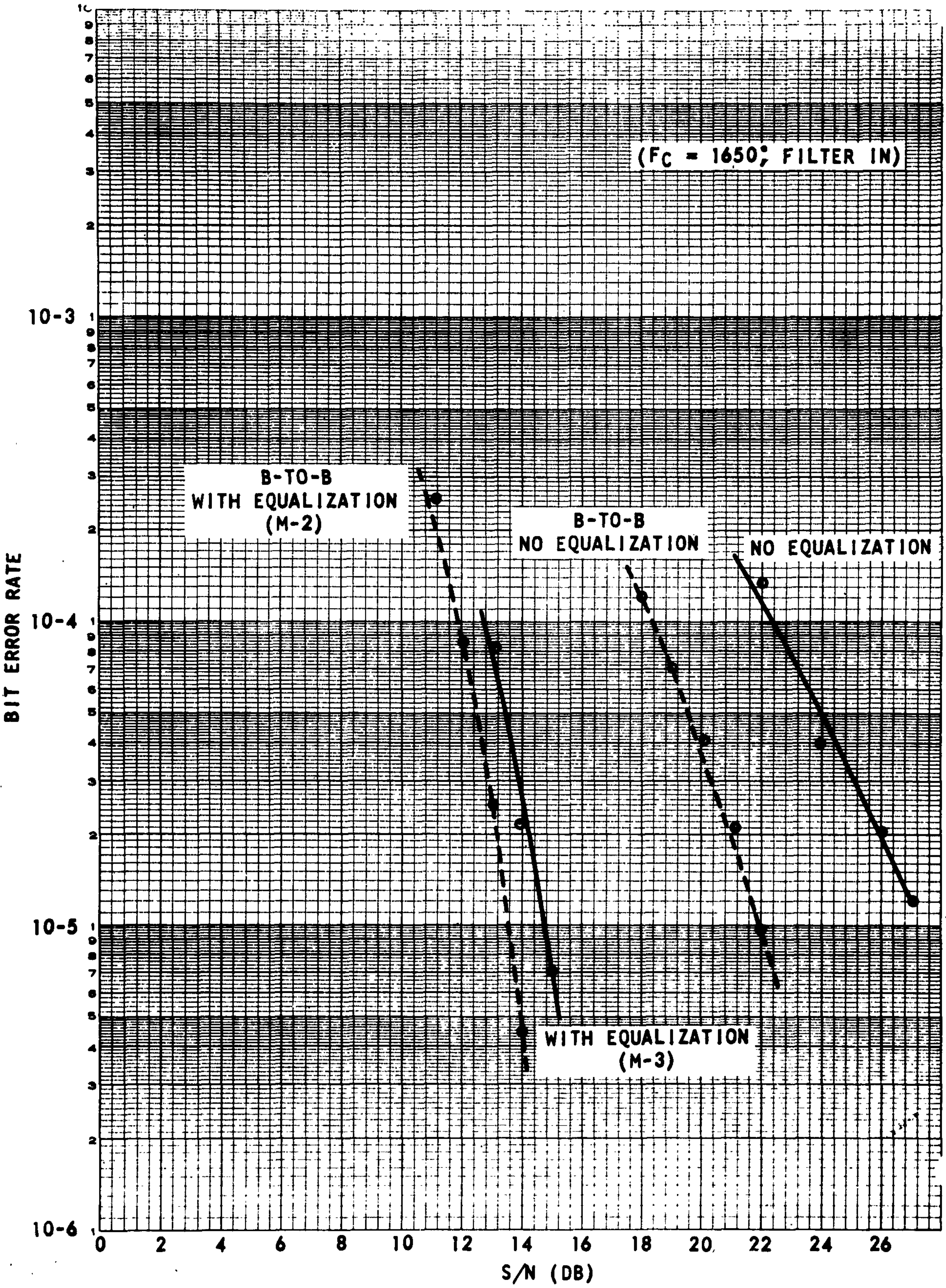


Figure 19. White Noise Performance of Quad-Phase Modem Over AN/TCC-7, 2400 bps

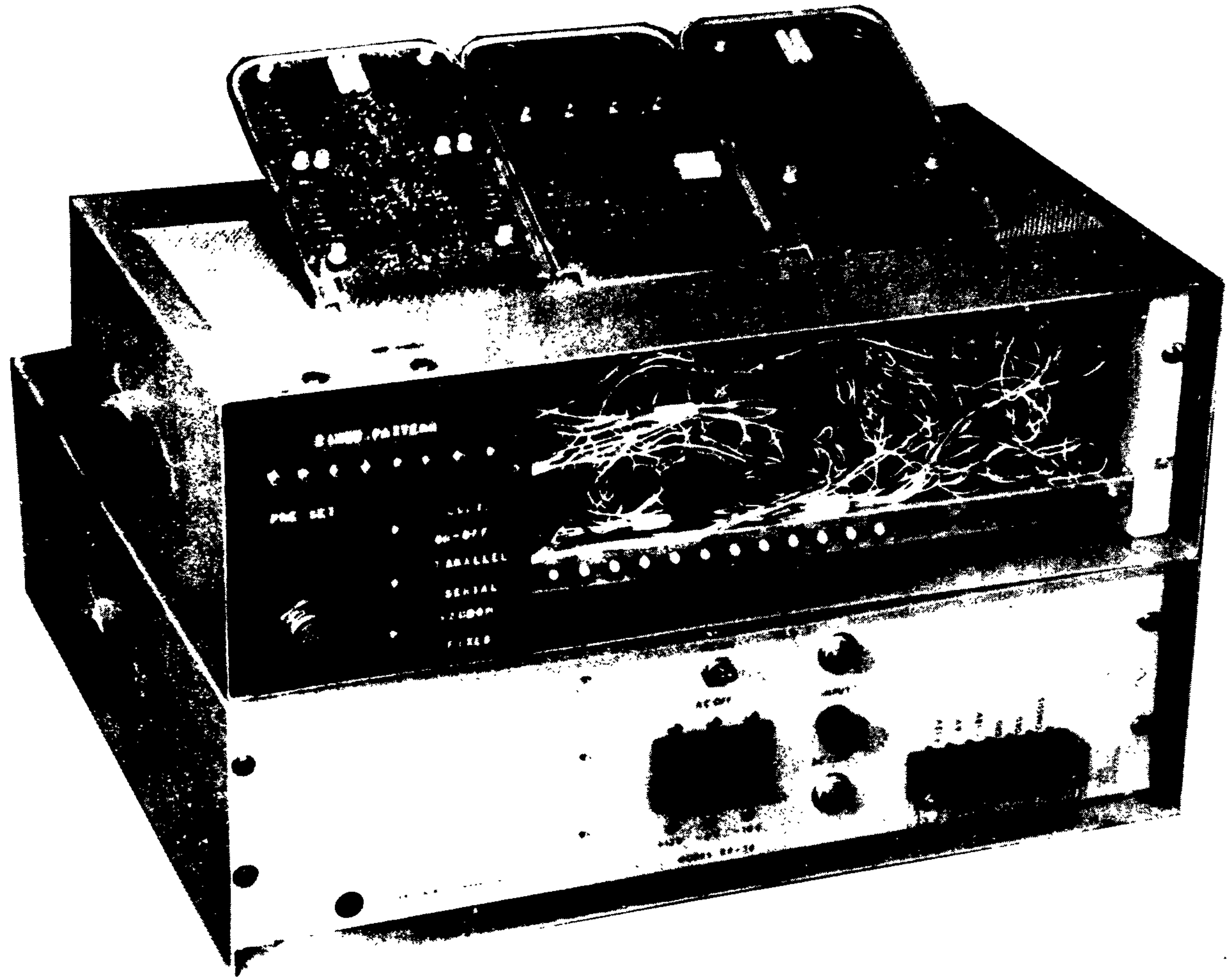


Figure 20. Data Generator and Power Supply

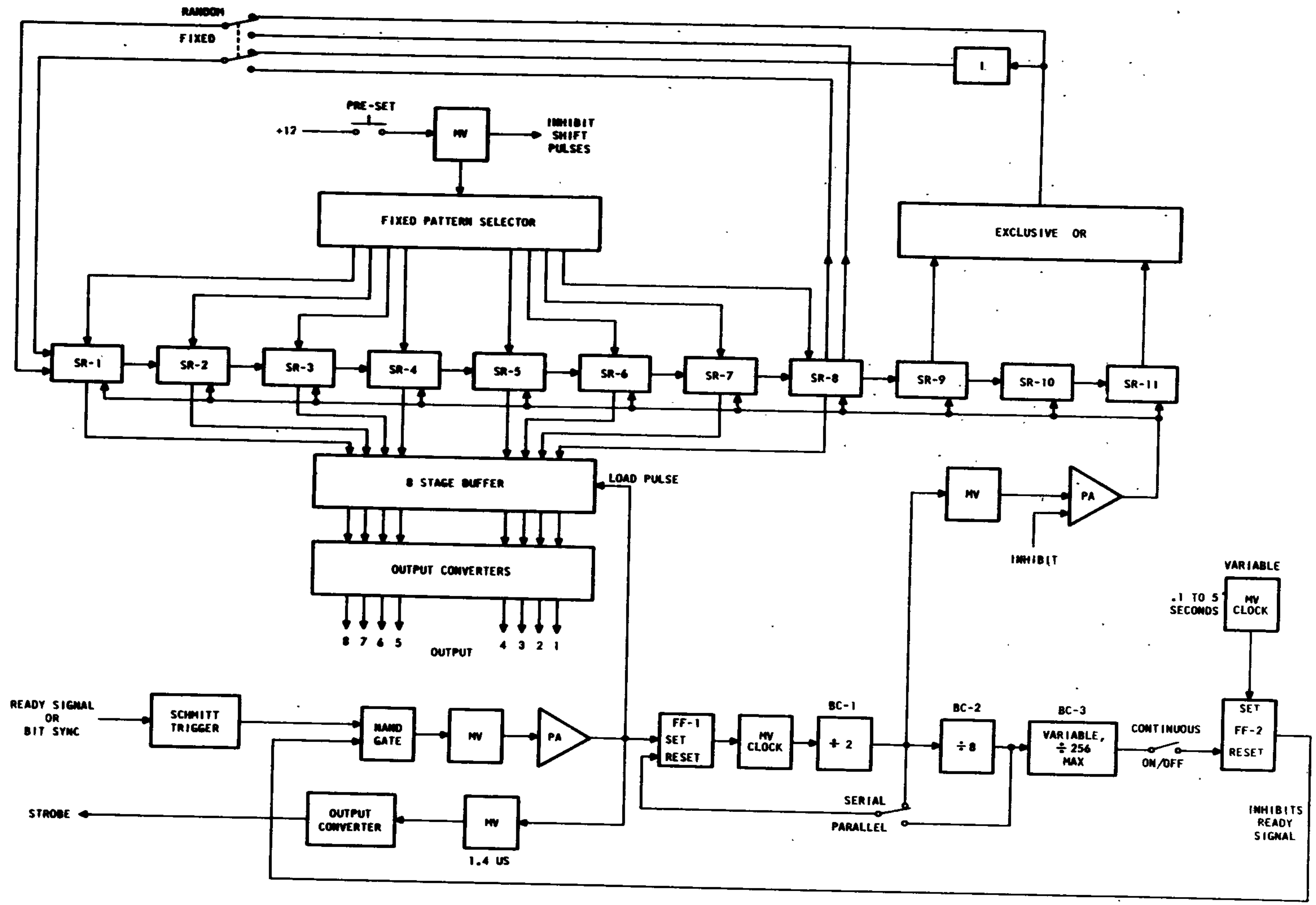


Figure 21. Data Converter, Block Diagram

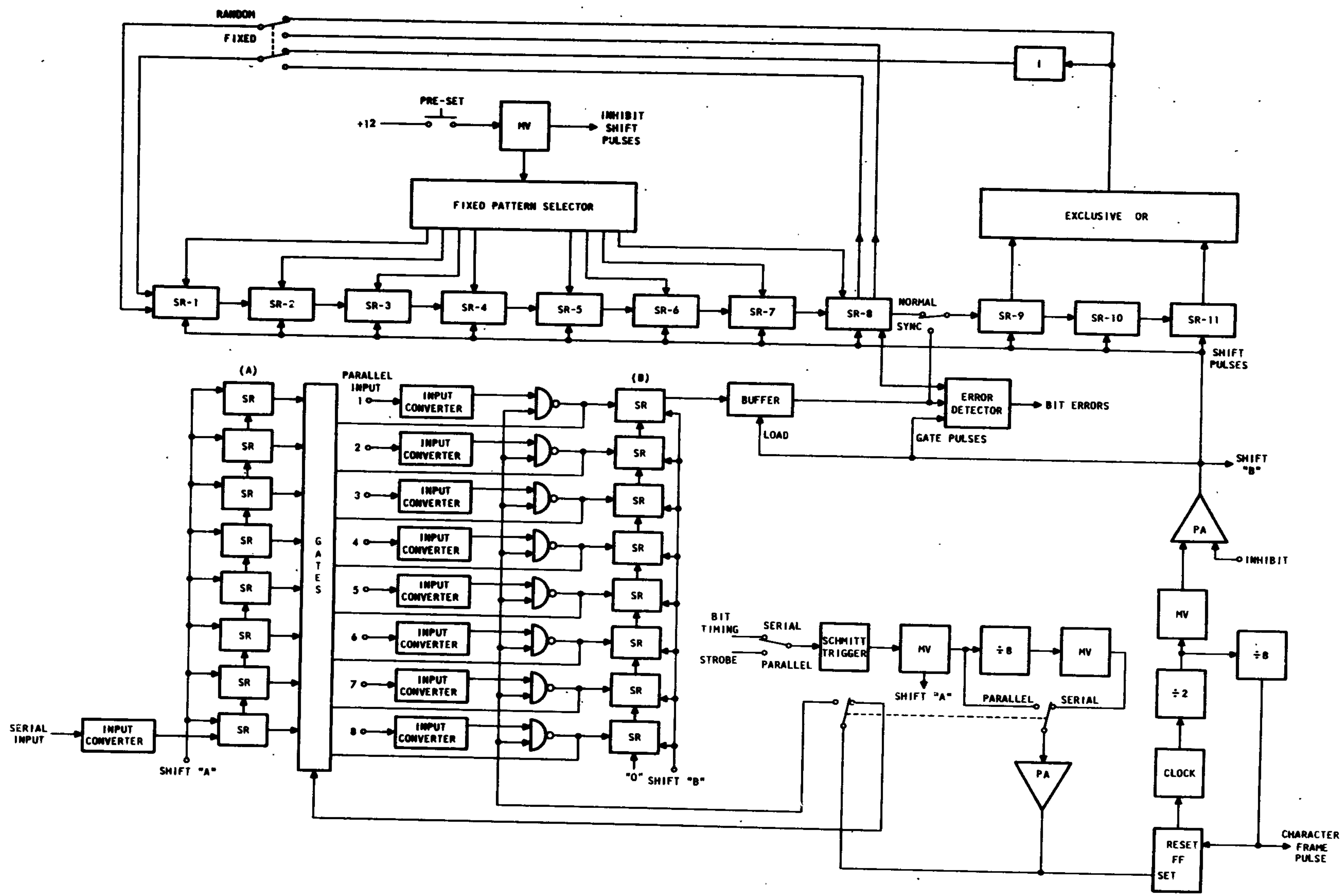


Figure 22. Data Correlator, Block Diagram

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FORT MONMOUTH, NEW JERSEY

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This document reports on the study of digital data transmission over existing military voice communications systems. Frequency translation tests of the modems are presented. Operational tests of the modems with the AN/VRC-12 and AN/TCC-7 are discussed. The design of the new generator and correlator is described.

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2. Contract No. DA 36-039-SC-90728 (continuation of Contract No. DA 36-039-SC-87343)

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